The Ganymede Laser Altimeter – Instrument design overview with radiation hard transmitter

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DLR

Structure

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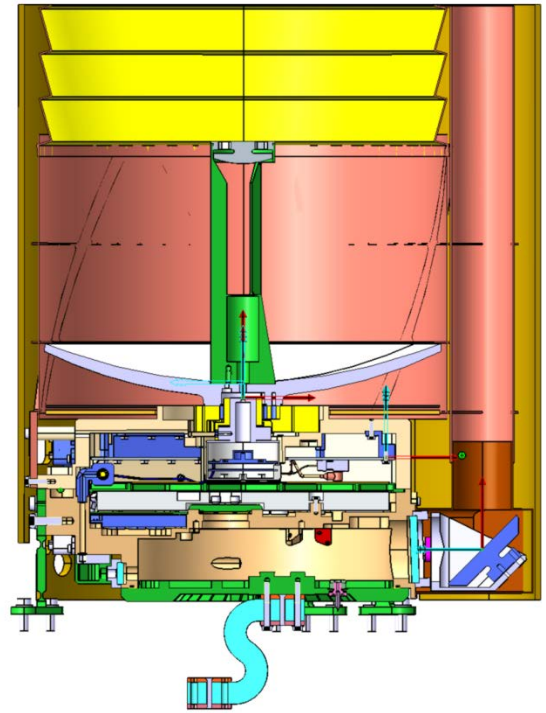
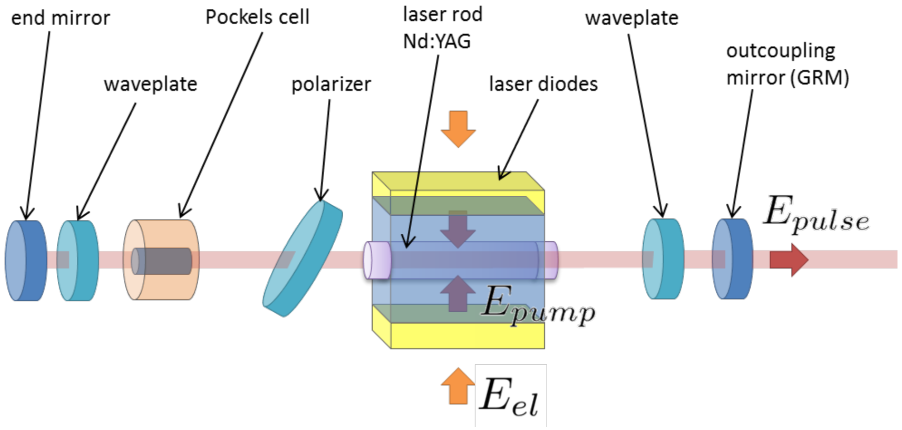
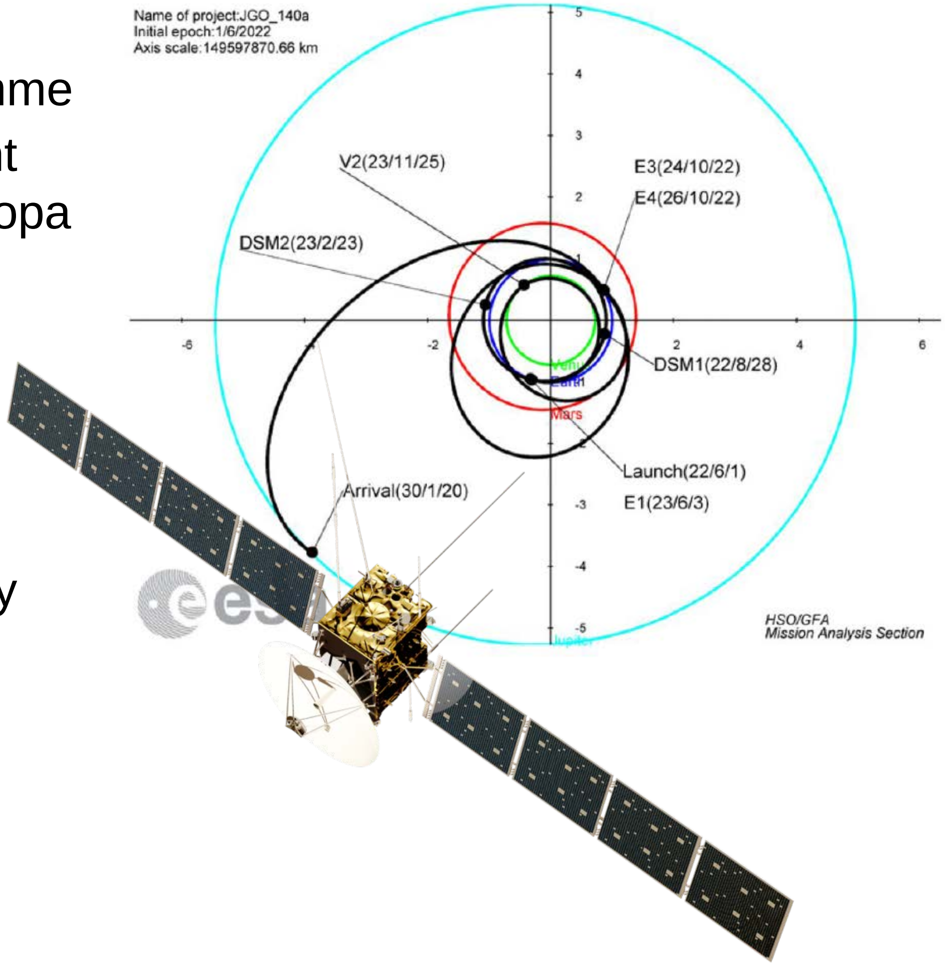




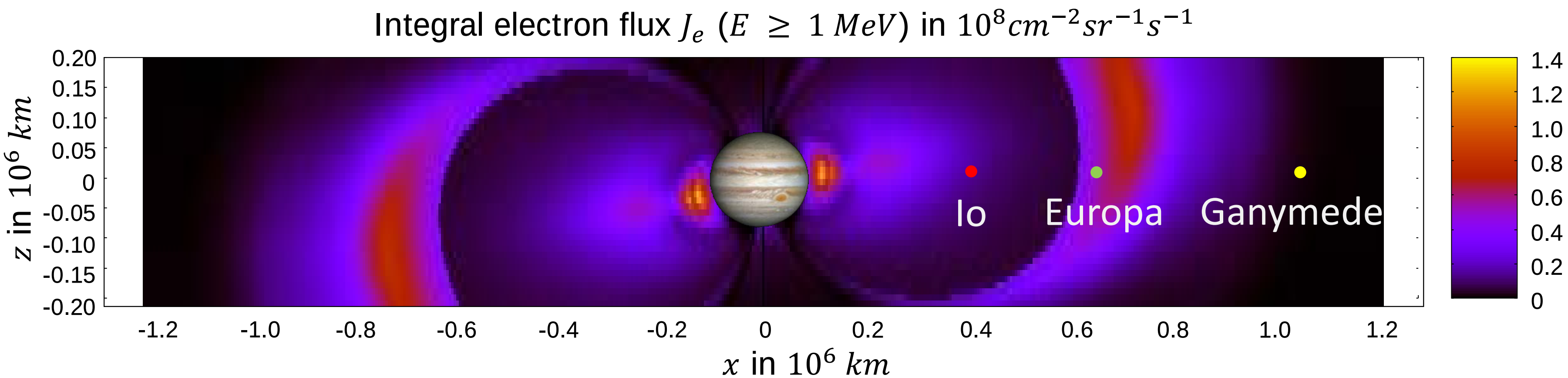
JUICE mission

- part of ESA‘s Cosmic Vision Programme
- to study Jupiter‘s plasma environment and the 3 icy moons Ganymede, Europa and Callisto
- S/C shall be launched in 2022 on an Ariane 5 rocket
- 8 year cruise phase with fly-bys at Venus, Earth and Mars
- then 3 years the orbit will be gradually adjusted, several fly-bys at Callisto, Europa and Ganymede
- finally 500 km circular orbit around Ganymede for 150 days
- 10 scientific instruments onboard



Credit: ESA/SRE(2014)1; JUpiter ICy moons Explorer; Definition Study Report

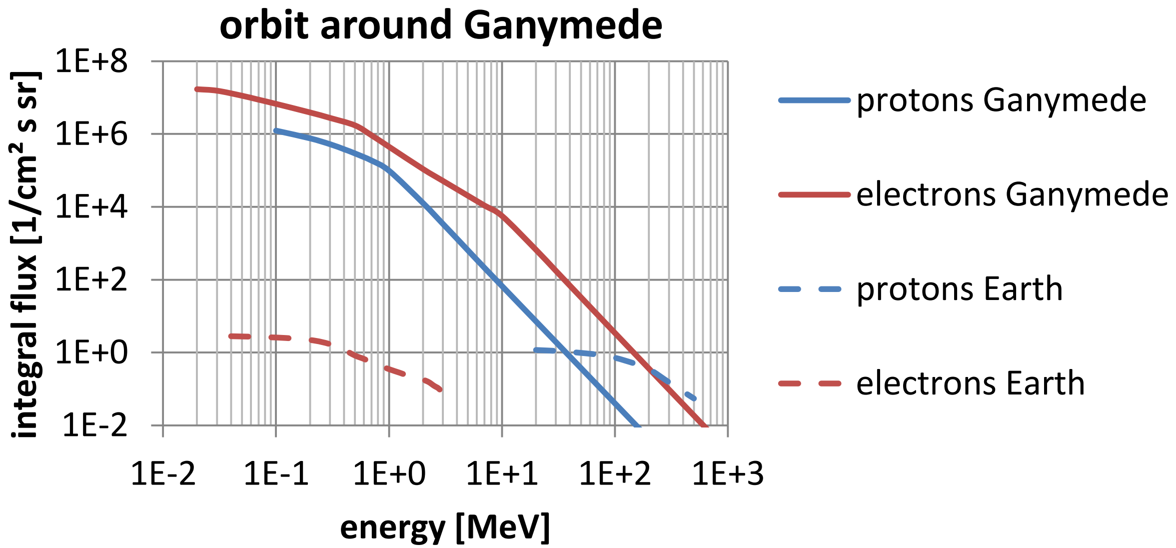
JUICE environment



Radiation Dose over mission:

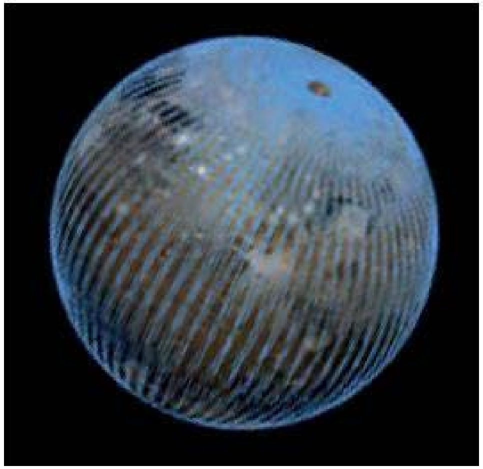
- unshielded instrument
  TID > 200,000 krad
- spherical shielding of 20 mm Al
  TID ~ 60 krad

(cf. simulation values are between 30…60 krad)

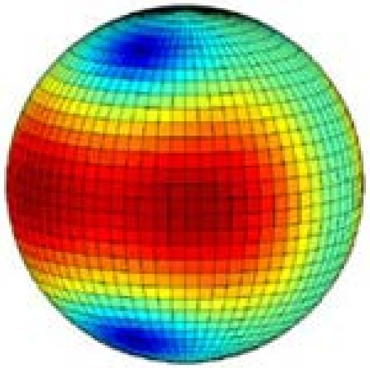


GALA science goals

- **Topography**
  - Global topography up to degree and order 40
  - Vertical resolution < 5 m
  - Test for hydrostatic equilibrium by measuring
  - Regional 10 - 50 km spacing between the tracks
  - Locally < 10 km spacing between the tracks
- **Measure radial tidal deformations**
  - Tidal Love number h2 with an absolute accuracy < 0.03
  - Constrain the ice shell thickness to ± 20 km.
  - Goal: Constrain the tidal phase-lag
- **Determine the satellite‘s dynamical rotational state**
  - Obliquity
  - Rotation rate
  - Longitudinal librations
  - Drift of the rotation axis
- **Regional slopes & roughness**
  - Slope from spot to spot
  - Roughness inside a laser footprint (~ 30 m)
- **Albedo at the laser wavelength (1064 nm)**

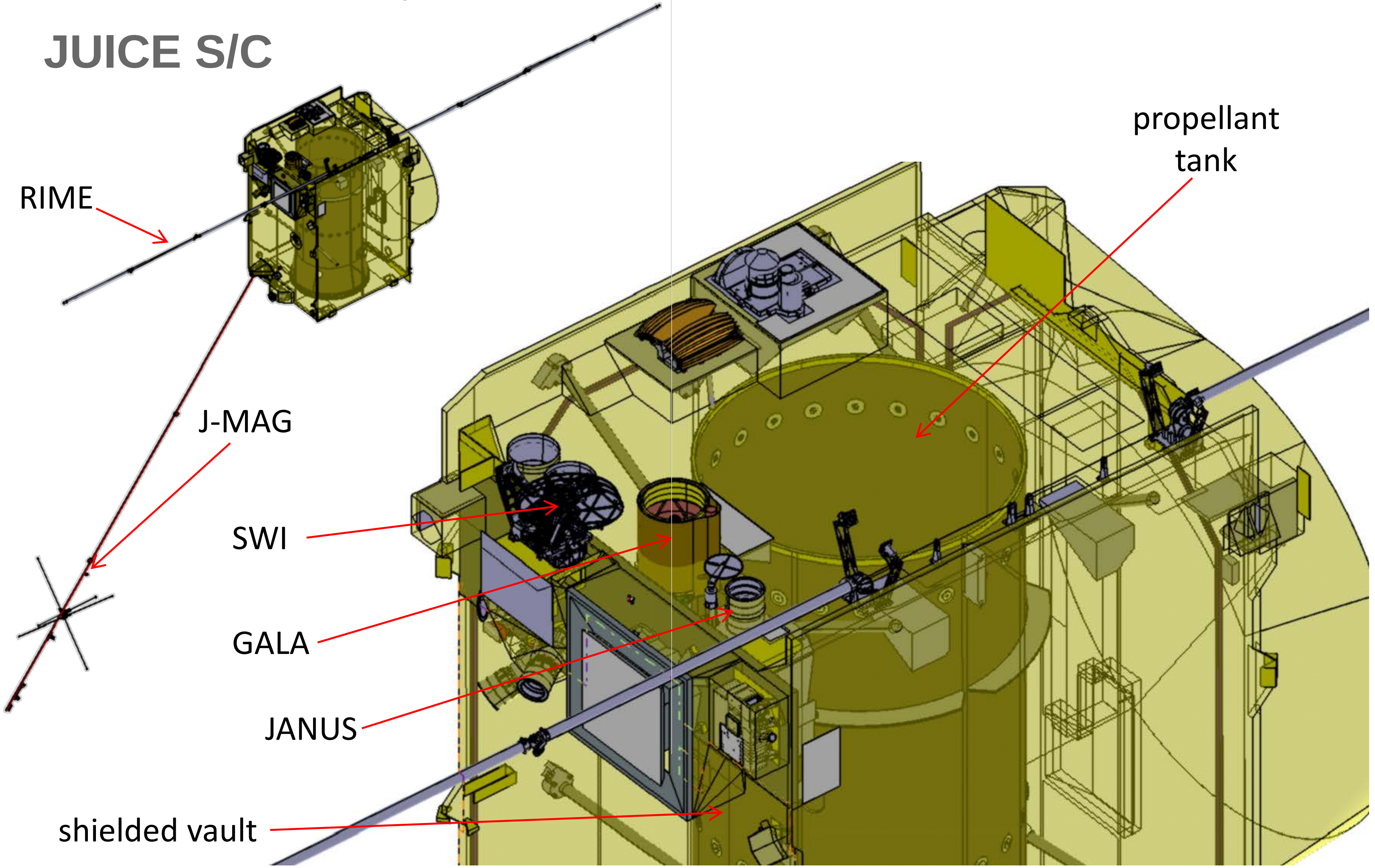


Global coverage for shape and tidal deformation (not all tracks are shown)



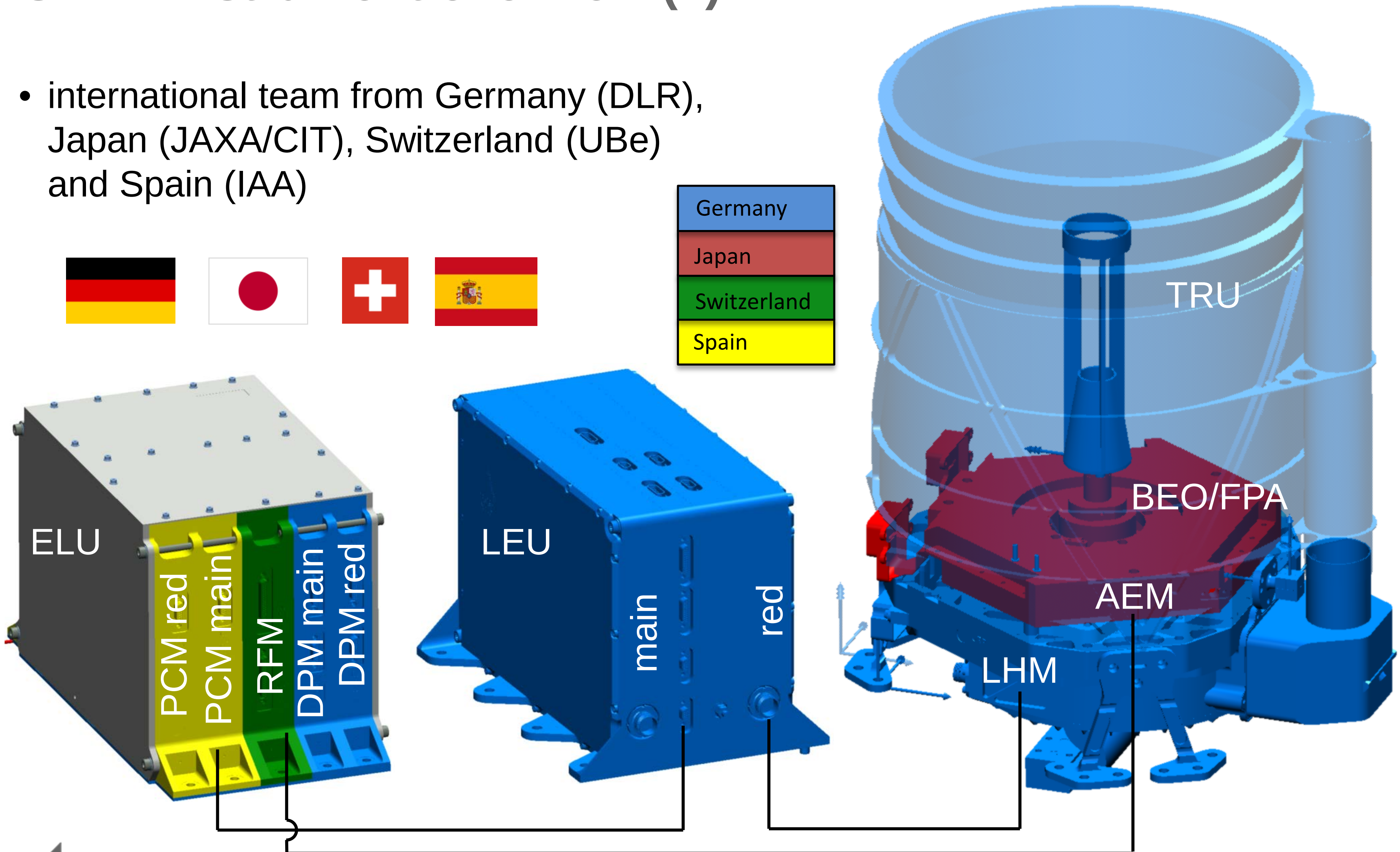
Maximal radial tidal deformation

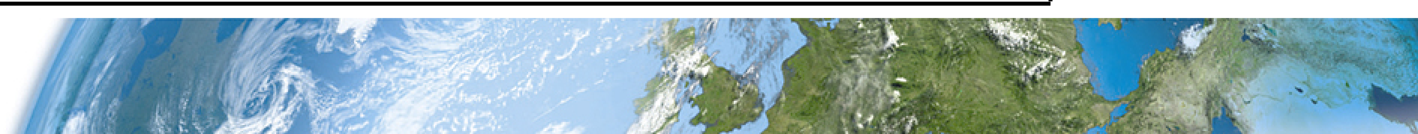
JUICE S/C



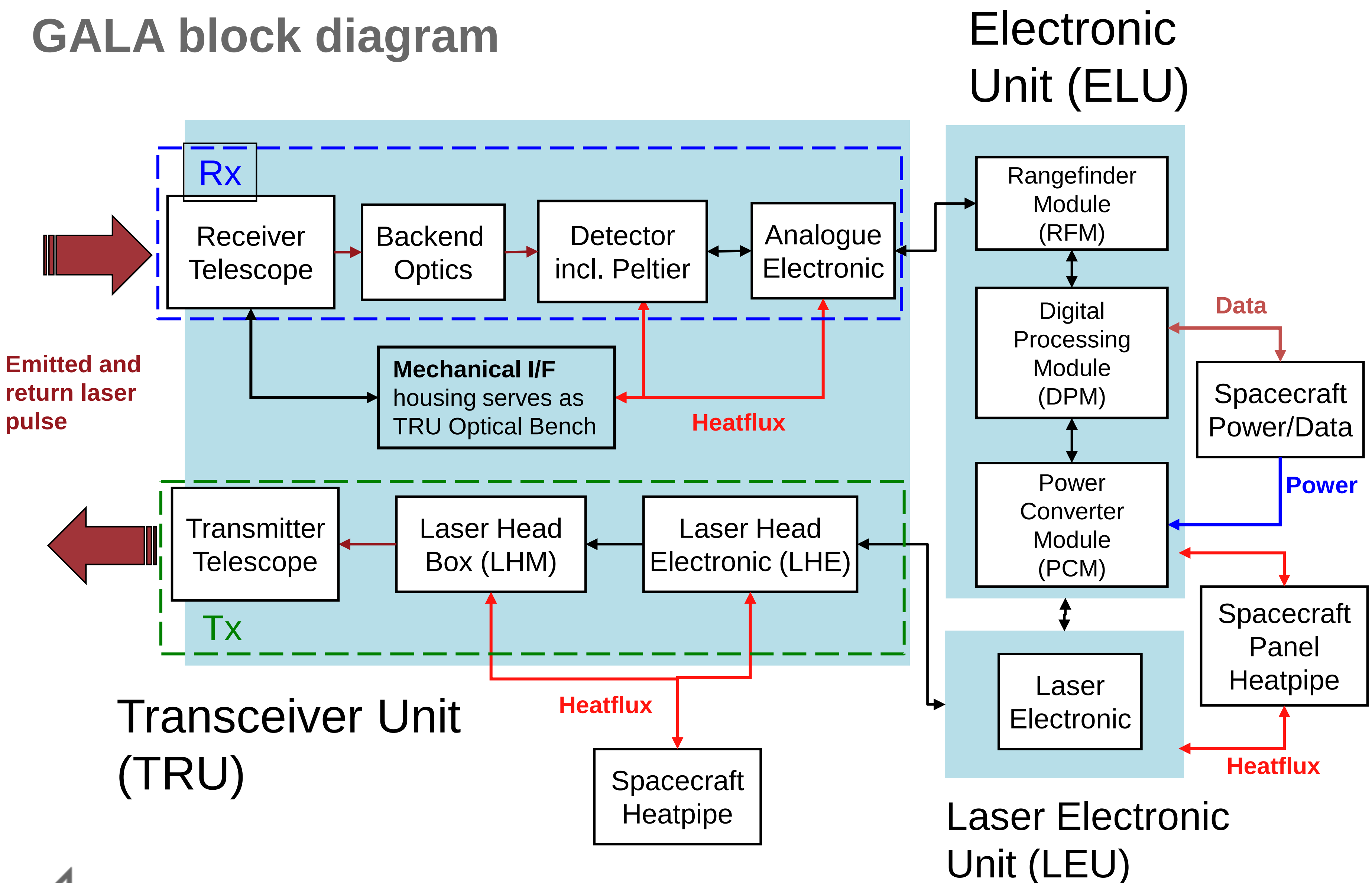
GALA instrument overview (1)

- international team from Germany (DLR), Japan (JAXA/CIT), Switzerland (UBe) and Spain (IAA)



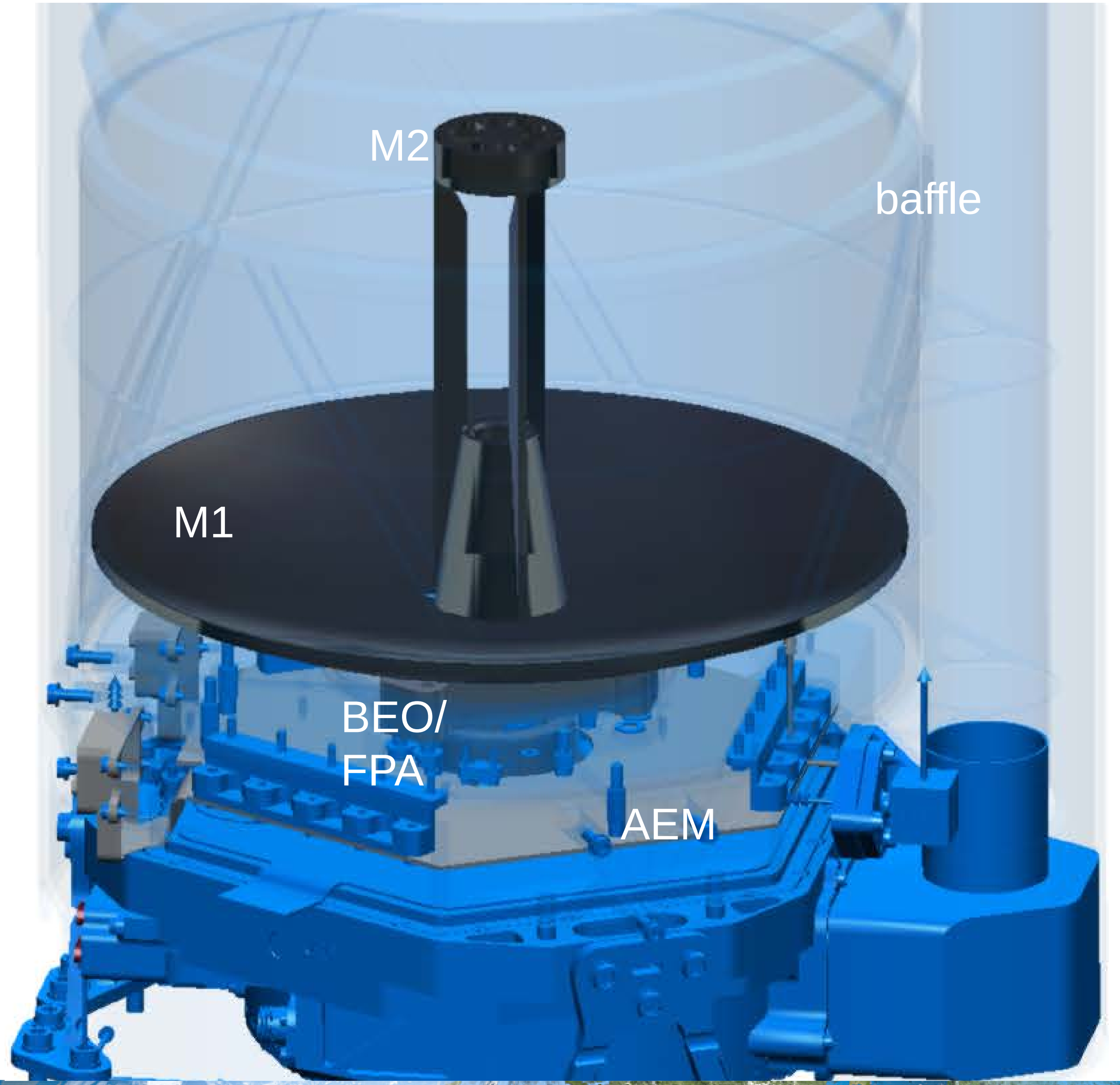


GALA block diagram



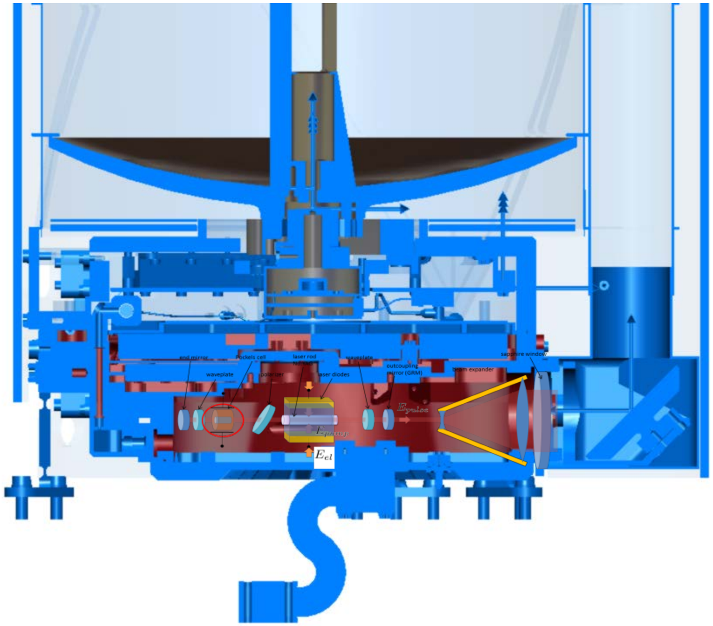
Receiver module

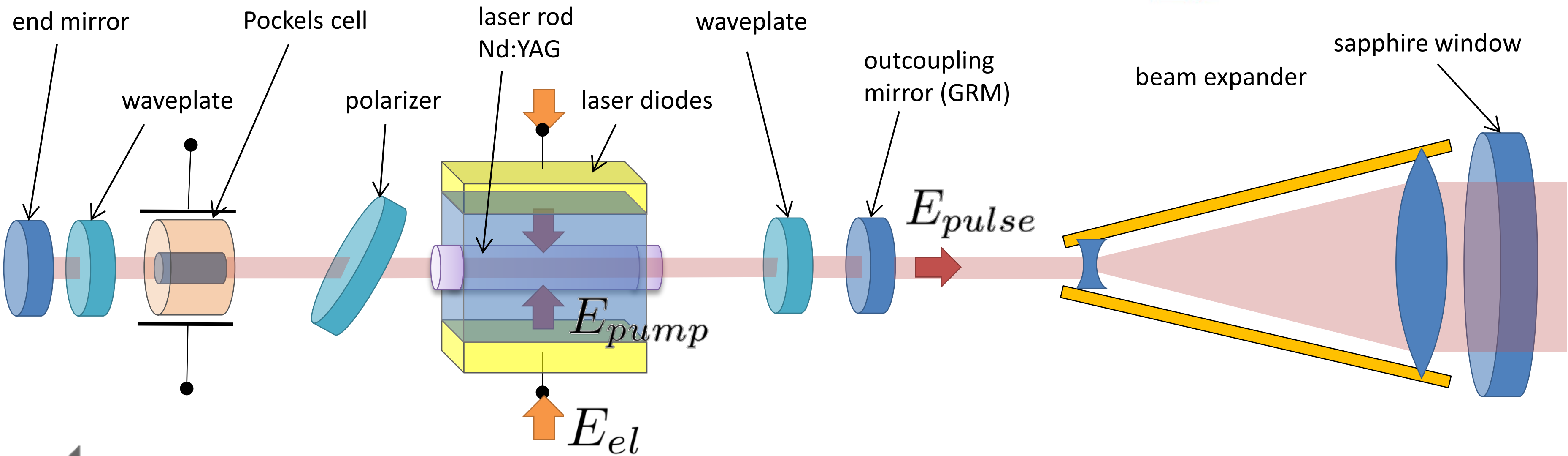
- Ritchey–Chrétien telescope
- 25 cm diameter
- lightweight design
- gold surface coating
- protection by straylight baffle for RX and TX
- backend optics with 1064 narrow bandpass filter and focal plane assembly with APD
- 200 MSamples per sec digital output
- digital filter matching in ELU RFM



Transmitter laser

- drivers: radiation hardness, efficiency, reliability, pulse properties, volume/mass
- different laser rods tested (up to 2 Mrad)
- optical coatings robustness and LIDT tested
- electric discharge effects of glasses and coatings not observed for 10 nA/cm²
- laser diode performance under radiation in evaluation programme





Laser cavity

- cavity optimization for low threshold and high slope
- Nd:YAG emits at 1064 nm; provides good optical properties; good absorption at 808 nm

pulse energy

mode area

small signal gain

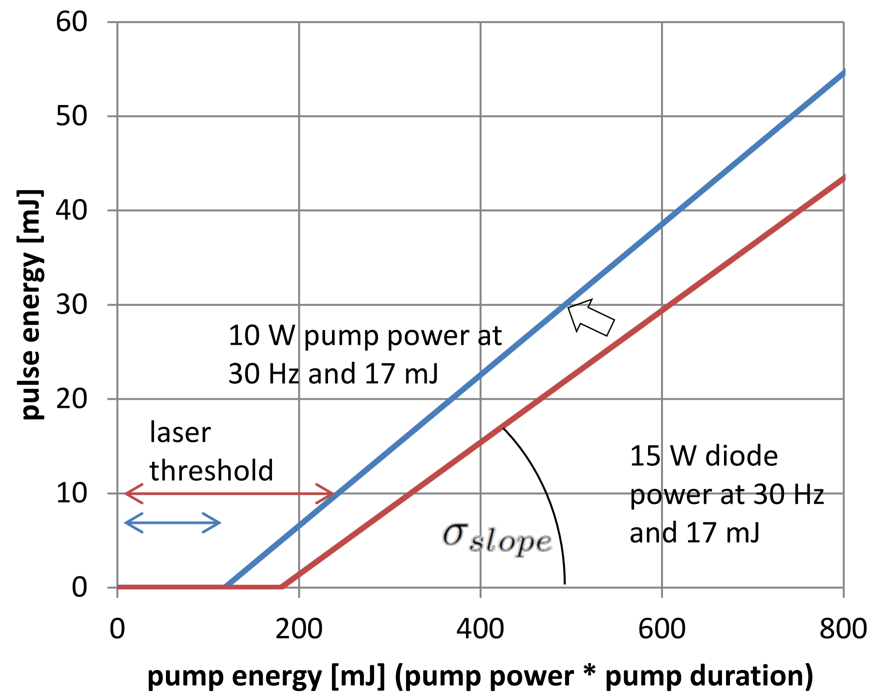
$$\uparrow E = \frac{\uparrow Ah\nu}{2\sigma\gamma} \ln \frac{1}{R} \ln \frac{n_i}{n_f} \uparrow$$

$$\downarrow P_{thr} = \left(\frac{L - \ln R}{2} \right) \frac{\downarrow Ah\nu}{\eta\sigma\tau_L}$$

$$\uparrow \sigma_{slope} = \left(\frac{-\ln R}{L - \ln R} \right) \eta \uparrow$$

pump efficiency, overlap efficiency, diode efficiency, quantum efficiency

Laser energy vs. pump energy



DLR

Laser rod Nd:YAG w/ and w/o Cr^{3+}

- Cr^{3+} co-doping of Nd:YAG is considered as radiation resistant
- effective energy transfer mechanism from Cr^{3+} to Nd^{3+} is known (Kiss and Duncan, 1964)
- color center formation due to iron impurities ($Fe \rightarrow Fe^{2+}$) during ionizing radiation (UV and gamma) (Glebov, 2010)
- when co-doped with Cr^{3+} ionization creates first further ionization of chromium
- positive effect of Cr^{3+} could not be verified
  - due to high quality of Nd:YAG rods
  - furthermore lifetime reduction of Nd with Cr^{3+} is reported

→selected rod material: Nd:YAG

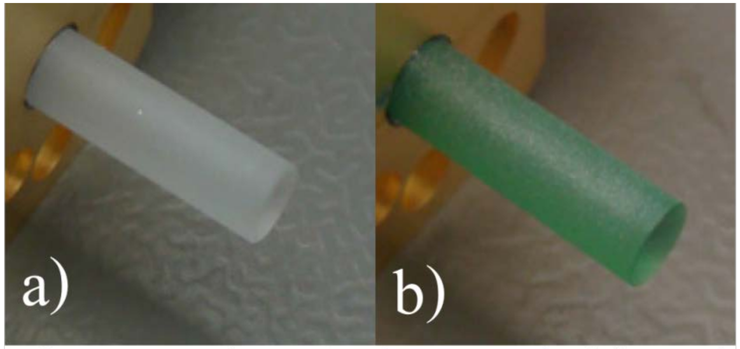
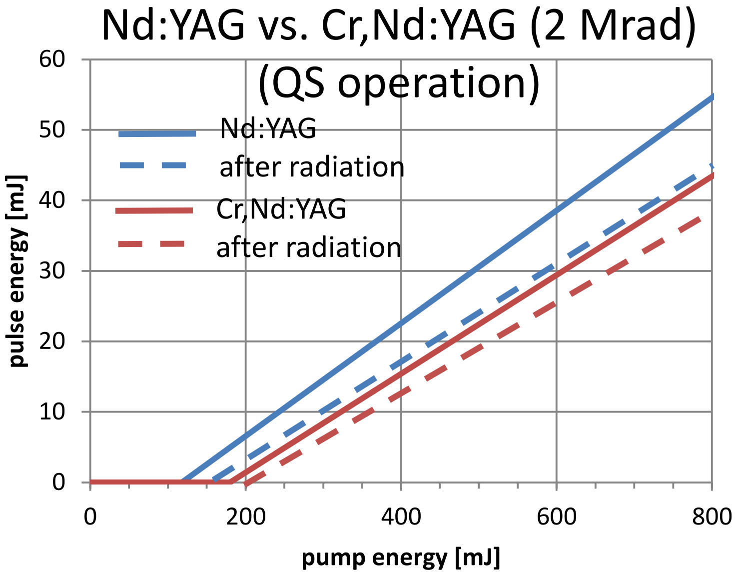
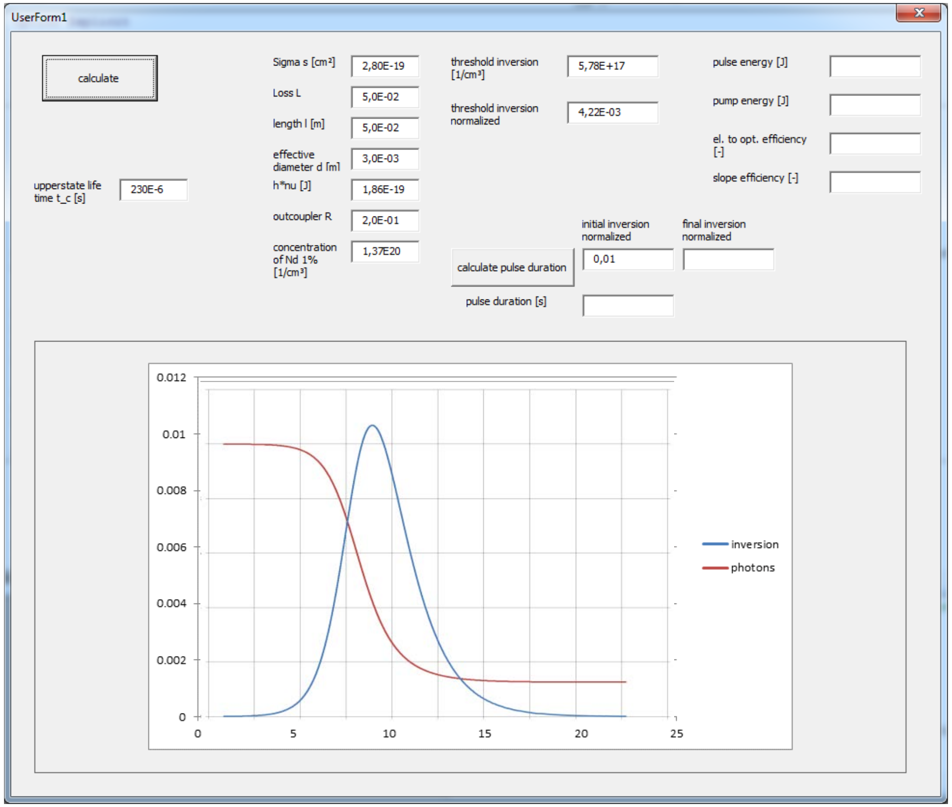


Fig. 5: Nd:YAG laser rod (a) and Cr3+,Nd:YAG laser rod. It was figured out that the Nd:YAG performs better in the GALA instrument.



Tools and models

- laser performance model that reflects the influences of design, environmental and degradation factors
- based on four level laser rate equations and adjusted by experimental data
    - electrical measurements data from breadboard as input
    - optical data after irradiation
    - degradation of electrical performance of opto-elctronic devices
- SPENVIS databases provides data about the radiation environment and models for radiation effects and charging
- GRAS and FastRad simulations



Conclusion

- highly demanding radiation environment and long mission duration
- thick shielding is mandatory → compact and mass efficient TRU design (4 kg shielding in a 12 kg unit)
- extensive testing of components (optical/opto-electronic) done for qualification
  - especially 3 and 15 MeV electrons tests
  - TID <u>and</u> TNID
  - protons play secondary role
  - charging effects likely not critical
  - noise effects on APD
- efficiency of the laser depends strongly on small signal gain and low lasing threshold
  - optimization of laser cavity design
  - 200 A drive current for laser diodes
  - short pockells cell rise time ~10…15 ns
- Nd:YAG rod without Cr^{3+} provides better overall performance
- optical to optical efficiency is ~0.09; electrical to optical ~0.04
- LDA qualification programme running

Thank you
for your attention!